Local Area Network for Distributing Data Communication, Sensing and Control Signals

FIELD OF THE INVENTION

The present invention relates to the field of wired communication and control networks, and, more particularly, to local area networks and networks used for sensing, communication, and control.

BACKGROUND OF THE INVENTION

Local area networks (LANs) for distributing data communication, sensing, and control signals are often based on a "bus" topology, as shown in Figure 1. Such a network **10** relies on shared electrically-conducting communication media **1**, usually constituted by a twisted-pair of electrical conductors or a coaxial cable. Network data terminal equipment (DTE) units **5**, **6**, and **7** are connected via respective network adapters **2**, **3**, and **4** to communication media **1**. Network adapters **2**, **3**, and **4** function as data communication equipment (DCE) units, and are tapped into communication media **1**, forming parallel electric connections, and thereby interface between DTE units **5**, **6**, and **7** and communication media **1**. Such network adapters are also commonly referred to as "NIC", an example of which is the Network Interface Card IEEE 802 (Ethernet). Such a topology is commonly used for connecting personal computers (PCs) in a network. Network adapters can be stand-alone units, integrated into the DTE unit or housed therewith in a common enclosure.

Control networks, interconnecting sensors, actuators, and DTE's also commonly use the same topology, such as the network described in US Patent No. 4,918,690 (Markkula, Jr. et al.) and shown in Figure 2. In a network **20**, network adapters **22, 23,** and **24** function as DCE's, but are commonly referred to as "nodes". The payloads **25, 26,** and **27** are composed of sensors, actuators, and DTE's.

Hereinafter, the term "node" is used for both control and data-communication applications.

A topology (such as bus topology) whose physical layer communication media employs multi-point connections, is not optimal for communication, and exhibits the following drawbacks:

1. The maximum length of the communication media is limited.
2. The maximum number of units connected to the bus is limited.
3. Complex transceivers are required in order to interface the communication media.
4. The data rate is limited.
5. Terminators are required at the communication media ends, thus complicating the installation.
6. At any given time, only single connected unit may transmit; all others are receiving.
7. In case of short circuit in the bus, the whole network fails. Localizing the fault is very difficult.

Despite these drawbacks, however, bus topology offers two unique advantages:

1. If the application requires "broadcast" data distribution, where the data generated by a given node must be distributed to all (or a majority of) the nodes in the network, network operation is very efficient. This is because only a single network operation is required (i.e., to establish which node is the transmitter). The

broadcast data is received by all other nodes in the network in parallel without additional network overhead.

2. The broadcast message is received simultaneously by all receiving nodes in the network. This is important in real-time control applications, for example, where orderly operation of the units must be maintained.

The communication-related drawbacks described above are solved by networks constructed of multiple communication links, wherein each instance of the link communication media connects only two units in the network. Here, the physical layer in each segment is independent of other links, and employs a point-to-point connection. Data and/or messages are handled and routed using data-link layer control. One example of such system for LAN purposes is the Token-Ring, described in the IEEE 802 standard. An example of a corresponding control network is described in US patent 5,095,417 to Hagiwara et al. Both networks use circular topology ("ring topology") as illustrated in Figure 3. A network **30** interconnects nodes (or NIC's) **32, 33,** and **34** by three separate cables **31A, 31B,** and **31C**, each connecting a pair of nodes and forming three distinct physical layer communication links. Payloads (or DTE's) **35**, **36,** and **37** are respectively connected to the appropriate nodes.

Both the Hagiwara network and the Token-Ring network use unidirectional communication in each communication link and require a circular topology. The PSIC network described in US Patent 5,841,360 to the present inventor teaches a similar network where the use of a circular topology is optional, and bi-directional communication (either half-duplex or full-duplex mode) is employed in the communication links.

The above-mentioned prior art patents and networks are representative only. Certain applications are covered by more than one issued patent. Additional discussion concerning the above-mentioned topologies can be found in U.S. Patent 5,841,360 entitled "Distributed serial control system" which issued November 24, 1998 and co-pending U.S. Patent application 09/123,486

filed July 28, 1998, both in the name of the present inventor, and incorporated by reference for all purposes as if fully set forth herein.

Networks such as those illustrated in Figure 3 typically use a "store and forward" mechanism, wherein the data received at a specific node is decoded at least to the data-link layer, and then re-encoded and transmitted to another point in the network as determined by the network control. This use of point-to-point communication links eliminates the communication drawbacks enumerated above in broadcast-based networks, but it lacks the two unique advantages of the broadcast technology, as also previously enumerated. Because the data is not inherently distributed throughout a network based solely on point-to-point communication links, such a network incurs a heavy overhead when broadcast is needed and exhibits delays in the propagation of messages. The overhead and delays result from the need to decode and re-encode messages at each node.

There is thus a widely-recognized need for, and it would be highly advantageous to have, a means of implementing a network which allows for both improved communication characteristics, while also supporting broadcast discipline and fast message distribution along the network.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a local area network in which at least some of the drawbacks described above are reduced or eliminated.

To this end, the present invention provides a local area network based on nodes connected to payloads. The nodes are interconnected to form a network of half-duplex or full-duplex communication links based on electrically conducting communication media such as twisted conductor pairs or coaxial cables. Each communication link interconnects two nodes in the network. Each node is capable of being dynamically configured as a transmitter or as a receiver. In addition, however, each receiving node can also be dynamically

configured to be a repeater, which simply retransmits the received data. In this way, data from one link can be repeated to all other links via an automatic multicast process. In normal operation, a specific node is selected as the data generating unit to transmit data to the network. All other nodes serve as repeaters and receivers, and hence the data is multicast instantaneously from the selected data generating node throughout the network. After completing this transmitting session, another node may be selected as the data generating node, with all other nodes serving as repeaters and receivers in a like fashion.

A network according to the present invention can also be configured in a circular topology, enabling operation to continue even when there is a malfunction or loss of a communication link.

Therefore, according to the present invention there is provided a local area network for distributing data communication, sensing, and control signals, the local area network including at least three nodes having an operational mode and interconnected by at least two distinct communication links according to a topology, wherein: (a) each of the communication links has at least two electrical conductors; (b) each of the communication links connects two of the nodes in a point-to-point configuration; (c) each of the communication links is operative to communicating in a half-duplex mode; (d) at least one of the nodes is connected to a payload; (e) at least two of the nodes have the operational mode selectable as a data-generating operational mode; (f) at least one of the nodes has the operational mode selectable as a repeating operational mode; and wherein the local area network has a state selectable from a group of at least two distinct states, wherein each state is characterized by having a single selected one of the nodes in the data-generating operational mode, with the remainder of the nodes in operational modes selected from a group containing the receiving operational mode and the repeating operational mode.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, some preferred embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Figure 1 shows a prior-art LAN for data communication, employing bus topology.

Figure 2 shows a prior-art LAN for control, employing bus topology.

Figure 3 shows a prior-art network for control or data-communication, employing circular topology.

Figure 4 describes a general block diagram of a node according to the present invention.

Figures 5a, 5b, 5c, and 5d show different possible states of a node according to the present invention.

Figure 6 shows a state of a network according to the present invention.

Figure 7 shows a general block diagram of a node according to the invention, wherein power is also carried by the network.

Figure 8 shows a state of a network according to the present invention, wherein power is carried by the network and employing circular topology.

Figures 9a and 9b show different possible states of a node in circular topology network according to the present invention.

Figure 10 shows a block diagram of a node according to a preferred embodiment.

Figure 11 shows a block diagram of a node according to the present invention, supporting three line couplers.

Figure 12 describes various possible node states, and the respective required switches states for a node as shown in Figure 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The principles and operation of a network according to the present invention may be understood with reference to the drawings and the accompanying description. The drawings and descriptions herein are conceptual only. In actual practice, a single circuit can implement one or more functions; alternatively, each function can be implemented by a plurality of components and circuits. In the drawings and descriptions, identical reference numerals indicate those components that are common to different embodiments or configurations.

Figure 4 schematically shows a node **40** according to the present invention. Node **40** contains the following functional blocks:

- A power supply **41**, fed from a power source **52**, which converts incoming power to the voltage, or voltages, required by the node and the node's components. In addition, power supply **41** may also feed a payload **49** connected to node **40**. If used, this feeding function is carried out by a payload interface **48**. (For clarity, Figure 4 omits the individual connections distributing power from power supply **41** to the power-consuming blocks of node **40**.)
- A payload interface **48** which adapts node **40** to a specific payload **49**. Various payload types can be employed, such as sensors, actuators and data units, either analog or digital, functioning either as output or as input. For example:
  - Analog sensor. The payload consists of analog sensor used to measure any physical phenomena. In most cases, the payload interface contains an A/D converter.
  - Digital sensor. The payload is a switch, button, etc.
  - Analog actuator. In most cases, the payload contains a D/A converter controlling the parameters of the analog actuator.

- Data related unit. In the case of digital communication, the payload consists of DTE and the payload interface contains a DTE interface.
- Non-digital data. Data such as video, voice, analog communication or any other of data type. If analog data is input to the node, the payload interface is likely to use an A/D converter.

The above examples are not intended to limit in any way the general payload definition. Furthermore, multiple devices of various types can be used. In some cases, payload **49** may use power from node **40**. For example, the excitation voltage to analog sensor may be driven from the node power.

Some nodes in the network may not be connected to a payload, or may not have any payload interface at all. Nodes configured in this manner would be used as repeaters only, such as a node **90** in Figure 8. Repeater nodes can be used, for example, to extend the distance between nodes beyond the regular limit.

- Line couplers **42** and **43**, which interconnect node **40** with up to two other nodes, each via communication media **50** and **51**, respectively (also referred to as "lines"). Each communication media supports communication between two nodes of the network. For clarity only, the two ports are designated 'Left'-LT and 'Right'-RT. The right connection RT uses line **51** and connects via RT line coupler **43**. Similarly, the left connection LT uses line **50** and connects via LT line coupler **42**. Neither line coupler **42** nor line coupler **43** affects the communication signal. Line couplers may include connectors, protection devices, isolation (e.g. transformer) and other required functions, which are not normally associated with the communication signal itself.
- A transmitter **45**, which deals with the data to be transmitted, except for the physical layer functions (according to the OSI interconnection model).

This block can be implemented in hardware (CRC generation circuitry, for example) by software, or by both hardware and software.

- A receiver **46**, which deals with the received data, except for the physical layer functions (according to the OSI interconnection model). This block can be implemented in hardware (CRC error detection circuitry, for example), by software, or by both hardware and software.
- A control, logic, and processing unit **47**, which controls and monitors node **40** and network operation. This block interconnects with the controlled blocks in node **40** (for clarity, some lines are omitted from Figure 4). In addition, control, logic, and processing unit **47** can process data in the network, and also deals with the payload via payload interface **48**. Control, logic, and processing unit **47** is furthermore in charge of shifting a repeater/router **44** from one state to another, as detailed below.
- Repeater/router **44** deals with the physical layer characteristics of the communication signal. The repeater/router can be in various states, including a receive-only state and a transmit-only state. The signal is encoded and decoded, and is routed according to the control signals from control, logic, and processing unit **47**. Detailed explanation of the repeater/router **44** follows.

A node can be stand-alone or integrated into the payload. For example, in the case of personal computer, the node can be housed within the computer enclosure as an add-on card.

Figures 5a and 5b describe the various repeater/router functions by means of the possible states of a repeater/router during normal operation. As shown in Figure 5a, repeater/router **44** contains two units connected in series. A line receiver **44b** decodes the communication signal in the line into a digital signal which is fed to receiver **46** for analyzing the data-link and higher OSI layers. The digital signal is then fed to a line driver **44a** which encodes the communication signal again. The pair consisting of line receiver **44b** and line driver **44a** thus form a communication signal repeater which performs a

transparent routing of the communication signal from 'left' to 'right'. The delay between input and output is negligible, in the order of nano-seconds or micro-seconds.

Similarly, Figure 5b allows for a routing from 'right' to 'left'. The direction of repeater/router **44** is controlled by control, logic, and processing unit **47**, via control lines (omitted for clarity from Figure 5).

Whereas Figures 5a and 5b describe a node which does not generate any data (but only receives and transfers the data in the network), Figures 5c and 5d illustrate nodes in the transmitting state. In both cases, the node transmits data to both the right and left connections via the respective line coupler. In figure 5c, two line drivers **44a** are used, one for each direction. In figure 5d, a single line driver **44a** is used, driving both directions from a single unit. Both embodiments can be used interchangeably. In most cases, the line driver and line coupler characteristics will be the basis for selecting one configuration in preference over the other. For example, if the line driver is capable of driving a single line only, the configuration of Figure 5c should be used.

Figure 6 shows a network **60** according to the present invention. Electrically-conducting communication media of lines **61a**, **61b**, **61c**, and **61d** are used to interconnect the nodes. At least two conductors are used in the communication media. For example, coaxial cables or copper twisted-pairs may be used. For clarity only, the figures herein illustrate the use of a single twisted-pair in non-limiting examples.

Nodes **62**, **63**, **64**, **65** and **66** are all the based on node **40** as described previously. Nodes **62**, **65**, and **66** are in 'Right to Left' state as illustrated in Figure. 5b, whereas node **64** is in 'Left to Right' state, as illustrated in Figure 5a. Node **63** is the data generating node as in Figure 5c and 5d. The network in Figure 6 shows one possible state of the network, wherein node **63** is the data-generating node, while all other nodes serve as receivers and repeaters, receiving the data and re-transmitting the data to the next sequential node. In

order to support dynamic reconfiguration, nodes can simultaneously have more than one operational mode. In a non-limiting fashion, a node can have:

- a data-generating operational mode, wherein a node functions as a source of data, and transmits this data to other nodes;
- a receiving operational mode, wherein the node receives data from another node; and
- a repeating operational mode, wherein the node functions as a repeater of data received from one given node by re-transmitting this data to another given node.

While the network is functioning, the current operational mode of a node is selectable from the available operational modes. Some operational modes may be mutually exclusive, while others may be selected simultaneously. For example, the data-generating operational mode is exclusive of the repeating operational mode, whereas the receiving operational mode may be selected at the same time as the repeating operational mode.

In most applications, more than one node can serve as a data-generating node at different times. In such a case, the network states will be changed as a function of time according to predetermined logic and control, in order to allow each data generating node an opportunity to transmit. However, no more than a single node can serve as data-generating node at a time. While a node is serving as data-generating node, all other nodes states are accordingly set to be repeaters and/or receivers, to allow for data distribution along the network. Nodes located 'left' of the data generating node will be in a 'right to left' state, while nodes located 'right' of the data-generating node will be in a 'left to right' state.

It should be clear that, whereas the nodes at the network ends, the 'left-most' node **62** and the 'right-most' node **64** could use the same structure as shown in Figure 4 (and can be implemented in the same way as all other nodes in the network), the end nodes utilize only single line connection. Thus,

these end nodes can be implemented using a single line coupler and single line driver.

It should also be clear that one or more of the nodes in the network need not be connected to a payload, as is illustrated for node **65** in Figure 6. This may be the case where the attenuation in the line is too high (e.g. a line is too long), and a node serves mainly as a repeater. In such a case, payload interface **48** would not be required.

Network powering.

Figure 6 illustrates a network wherein each node is locally powered by a local power source **52**, which supplies electrical power for operating the components of the network. Alternatively, the network communication media can be used for power distribution. In one embodiment of the present invention, the power is distributed via dedicated lines, such as by the use of two additional wires within the same cable. In a preferred embodiment, the same wires can be used for both data communication and power distribution. The latter configuration is described in co-pending U.S. Patent Application 09/141,321, filed by the present inventor on August 27, 1998, which is applicable to the network discussed herein and incorporated by reference. Figure 8 illustrates such a network, allowing for single power-supply to be used for powering the whole network.

When the same wires are used for both communication and power, the node **40** should be modified to include a power/data combiner/splitter **71** as shown in Figure 7. A node **70** is shown with two power/data combiner/splitters **71** coupled to line couplers **42** and **43**. A node such as node **70** can receive power from either the left or the right sides or from both sides, and carry the power to the non-powered side. Being powered from the network, no power source interface will be usually supported for such a configuration. The power source feeding the network can connect thereto via dedicated couplers or via one or more of the nodes, modified to support such capability.

Circular Topology.

While the foregoing description applies the present invention to a linear topology, the present invention can also be implemented using a circular topology for 'ring' type networks. In one embodiment, both ends of the network are connected to a node which is configured to receive from both sides, hence including two receivers. However, Figure 8 shows a preferred embodiment of a network **80**. In network **80**, all nodes except the data-generating node are configured to the transparent repeater state, either uniformly 'right-to-left' or uniformly 'left-to-right'. A node **90** in the data–generating state is modified as illustrated in Figures 9a and 9b. Node **90** can transmit to one side and receive from the other. In Figure 9a node **90** can transmit to the left side and receive from the right side. Similarly, in Figure 9b node **90** can transmit to the right side and receive from the left side. Either state can be used in circular topology. In Figure 8, node **90** is in the state shown in Figure 9a. Alternatively, node **90** can be in the state shown in Figure 9b. All other nodes of Figure 8 are configured in the 'right-to-left' direction. In both cases, the data-generating node **90** transmits to one side and receives from the other. The receiving functionality of node **90** can be used for monitoring the network, to insure that the data path is available and is error-free. However, this receiver functionality is an option only, and does not have to be implemented.

For compactness, Figure **8** demonstrates both the power feeding via the network and the circular topology together, but these features are independent and may be implemented separately.

Network Control.

As described above, the operation of the network (either bus or circular topology) switches from state to state. Each state is characterized by having a specific node functioning as data-generating node at a time, while all other nodes serve as repeaters and receivers, routing the data coming from the

data-generating node. Hence, there is a need for a network controller to determine which node in the network will be the data-generating node.

Various techniques can be used to implement such a network controller. The network controller can select nodes sequentially, by means of token passing from node to node (similar to that of the Token-Ring network). The network controller can be external to the network, using dedicated communication media. Preferably, the network controller will be embedded and will manage the network states via signals transported by the network itself. In most cases, each node should be allocated an address, enabling data routing in the network from arbitrary node to arbitrary node.

Another popular method of network discipline is 'master/slave' operation. In another embodiment of the present invention, one of the nodes will be designated as the master node. In the initial state, this node serves as the data-generating node, and while in this state directs other nodes to transmit. During the following state the selected node will serve as the data-generating node. This two-state sequence will be repeated, with a different node selected to be the data-generating node in each subsequent cycle, according to predetermined logic or under external control.

Dual discipline network.

The network taught by US Patent 5,841,360 to the present inventor, herein referred to as the "PSIC Network", employs multiple communication links, independent of each other. Such a network supports several features which are not available in the previously-described network, such as automatic addressing, fault localization, and circular topology redundancy in the case of single failure.

In order to exploit the benefits of both these network types it is possible to construct a network which supports both disciplines. and can be controlled to be either in one discipline or in the other. For example, the network may start as PSIC Network. During this start-up period, automatic addressing and fault

localization will be performed. Thereafter, the network may configure itself to work according to this application or may use time-sharing and alternately switch between both configurations.

Figure 10 shows a schematic view of a node **100** which is capable of both roles. The state of node **100** is determined by switches **101**, **104**, **102**, and **103**, designated SW1, SW2, SW3 and SW4 respectively. These switches are controlled by control, logic, and processing unit **47**. Node **100** employs transmitters **45a** and **45b**, as well as receivers **46a** and **46b**. Line driver **44a** serves the right port, while line driver **44a1** serves the left connection. Similarly, line receivers **44b** and **44b1** are connected to the right and left interfaces respectively.

Figure 12 lists the various possible node states for node **100** (Figure 10). The states in Figure 12 are given in a Node State column, and the switch settings are given in SW1, SW2, SW3, and SW4 columns. In a 'Right-to-left' state, data received in the right port is handled by line receiver **44b** and fed to line receiver **46b**. Simultaneously, the received data is fed to line driver **44a1**, which transmits to the left side. Thus, the functionality shown in Figure 5b is obtained. In a similar way, the 'Left-to-right' state is implemented to achieve a functionality as shown in Figure 5a. In the latter case, line receiver **46a** is the active one.

In the 'transmit both sides' state, transmitter **45a** transmits to both ports using line drivers **44a** and **44a1**, implementing the functionality shown in Figure 5c. In the 'receive both sides' state, each receiver is connected to single line coupler, and no line driver is activated. This is expected to be the state when the network is idle or as an interim state while switching between states, in order to avoid data collisions caused by two or more transmitters active over the same link.

The 'transmit right receive left' state reflects the state shown in Figure 9b. Similarly, the 'transmit left receive right' state reflects the functionality shown in Figure 9a.

In the 'transmit/receive both sides' state, the node can receive and transmit in both interfaces simultaneously, thus implementing the full PSIC Network functionality.

Nodes with More than Two Line Connections

Whereas the foregoing discussion describes a node having two line couplers (which may be reduced to single interface in the case of an end-unit in a network employing 'bus' topology), it is obvious that three or more such interfaces could also be used. In such a case, at least one additional repeater/router must be added for each additional interface. For example, Figure 11 illustrates a node **110** having three interfaces, where an additional interface is designated as 'up', and uses a line coupler **112** for interfacing to a line **111**. In order to support the interconnection between all three ports, three repeater/router units **44** are used, each constructed as described previously and suitable for connecting two ports. In some applications, where the connectivity requirements can be reduced, any two out of the three ports may be used.

Similarly, additional interfaces can be used. Furthermore, a network can employ nodes of different interface capacities, which can be freely connected to construct a network of arbitrary topology. In all cases, the basic rule that each communication link connect only two nodes must be observed. Furthermore, the network logic embedded in the nodes has to insure that no more than a single node generates data, while all others must be in the transparent repeater/router state, directed from the data-generating node.

Implementation.

Implementing any of the above schemes is straightforward for anyone skilled in the art. In one embodiment, RS-485 (EIA-485) is employed for the physical layer. In such a case, line driver **44a** and line receiver **44b** are directly implemented using a common RS-485 line driver or line receiver, respectively. Similarly, the switches illustrated in Figure 10 can be implemented using manually-activated switches, relays, analog switches, or digital switches/multi-

plexers. Except in the case of manual switches, switching is controlled electronically.

Repeaters and regenerators are known in both prior-art WAN (Wide Area Network) and LAN (Local area network) systems, mainly for the purpose of allowing operation over lengthy connections. However, there are major differences between those networks and the present invention. First, most prior-art repeaters employ single input and single output. The present invention allows for multiple ports. Second, prior-art repeaters are unidirectional, while the present invention is not restricted to a specific direction of data flow. Additionally, the present invention requires a control mechanism (a network controller) for determining the data flow direction, whereas prior-art systems, being unidirectional, do not require such control. In most prior-art networks, units in the network can be clearly defined as either payload-associated units or dedicated repeaters. Such a distinction is not valid when implementing a network according to the present invention, since each payload-associated unit in the network also includes the repeater functionality.

Although a network according to the present invention, when configured in circular topology, can be superficially similar to a Token-Ring network, there are major differences between them. In a Token-Ring network, there is a single constant direction of data flow. The present invention does not impose single direction of data flow, but the flow may change as part of the network operation. In addition, in Token-Ring networks the data-generating unit is sequentially allocated according to the network topology. In the present invention, the data-generating node need not be chosen according to any specific rule, although sequential selection of the data-generating node is possible.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.